CDF note 10878

Measurement of Top Dilepton Cross Section with CDF Full data the DIL Selection

The CDF Collaboration
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A measurement of the $t\bar{t}$ production cross section in $\mathrm{p\overline{p}}$ collisions at $\sqrt{\mathrm{s}}$=1.96 TeV using events with two leptons is reported. The data were collected by the CDF II Detector. The results in a dataset corresponding to an integrated luminosity 9.1 fb^{-1} for pre-tagged events and 8.8 fb^{-1} b-tagged events:

$$\sigma_{\mathrm{t\bar{t}}} = 7.60 \pm 0.44_{\mathrm{stat}} \pm 0.52_{\mathrm{syst}} \pm 0.47_{\mathrm{lumi}} \text{ pb}$$

for 579 pre-tagged signal candidate events

$$\sigma_{\mathrm{t\bar{t}}} = 7.09 \pm 0.49_{\mathrm{stat}} \pm 0.52_{\mathrm{syst}} \pm 0.43_{\mathrm{lumi}} \text{ pb}$$

for 246 tight SecVtx b-tagged signal candidate events

Preliminary Results for Winter 2012 Conferences

I. INTRODUCTION

This note describes a measurement of the $t\bar{t}$ production cross section in $\bar{p}p$ collisions at $\sqrt{\text{s}} = 1.96$ TeV with the CDF detector at the Fermilab Tevatron. The measurement is based on the identification of both leptons in the decay chain $t\bar{t} \rightarrow (W^+b)(W^-\bar{b}) \rightarrow (l^+\bar{v}_l b)(l^- v_l \bar{b})$. Therefore it selects decays with two high transverse energy leptons, high missing transverse energy ($\not\!\!E_T$) and at least two jets in the final state. The excess of events selected in the data over the background expectation from the other known Standard Model sources is taken as a measurement of the production of $t\bar{t}$ events.

This measurement provides a test of the QCD calculations of the $t\bar{t}$ cross section [1] in a channel which is independent and complementary to other measurements of the $t\bar{t}$ cross section using higher statistics final states in which at least one W boson from the top quark is reconstructed via its hadronic decay, $W \rightarrow q\bar{q}$. It is also the only final state with a favorable signal to background ratio.

The CDF detector is described in detail in [2].

II. DATA SAMPLE & EVENT SELECTION

This analysis is based on an integrated luminosity of 9.1 fb^{-1} collected with the CDF II detector between Feb. 2002 and Sep. 2011 for before requiring the identification of one of the jets in the final state as a jet from a b quark, called by the pre-tagged sameple. And after requiring the b-tagging, the integrated luminosity corresponds to 8.8 fb^{-1}. The data are collected with an inclusive lepton trigger that requires an electron or muon with $\mathrm{E_T}$ >18 GeV ($\mathrm{P_T}$ >18 GeV/c for the muon). From this inclusive lepton dataset, events with an offline reconstructed isolated electron of $\mathrm{E_T}$, or muon with $\mathrm{P_T}$, greater than 20 GeV are selected. A second electron of $\mathrm{E_T}$, or muon of $\mathrm{P_T}$, greater than 20 GeV is also required using looser identification cuts and no requirement on isolation. Events with more than two leptons in the final state are rejected. A Muon Track $\chi^2/ndf < 2.3$ cut is used for data events in order to remove unphysical events which have large transverse energy.

This "dilepton" dataset is cleaned of other known Standard Model decays with two leptons in the final states by requiring $\not\!\!E_T$ >25 GeV (or >50 GeV if any lepton or jet is closer than 20° from the missing $\mathrm{E_T}$ direction) and high missing $\mathrm{E_T}$ significance for ee and $\mu\mu$ events with dilepton invariant mass in the Z peak. And additionally we require the dilepton invariant mass to be larger than 5 GeV.

At this point of the selection, events reconstructed with 0 or 1 jets of $\mathrm{E_T}$ >15 GeV are used as a control sample for the background estimation. The $t\bar{t}$ candidate region is obtained by requiring at least 2 jets with $\mathrm{E_T}$ >15 GeV, summed transverse energy H_T >200 GeV and the two leptons to be of opposite charge.

A. Total $t\bar{t}$ Acceptance

The acceptance for candidate events is measured using the PYTHIA Monte Carlo program [3] simulating $t\bar{t}$ events with an assumed $\mathrm{M_{top}}$=172.5 GeV. The Monte Carlo selection is restricted to events with both W's from top decaying to a lepton plus neutrino, where the lepton can be any of e, μ or τ. Of the $t\bar{t}$ events with a reconstructed vertex along the z-direction inside ±60 cm of the nominal CDF detector origin (corresponding to 96.0% of full CDF luminous region), the acceptance for the pre-tagged candidate dilepton events is $\mathcal{A}$=0.756±0.004% and for the b-tagged events is $\mathcal{A}$=0.461±0.003%.

The $t\bar{t}$ Monte Carlo prediction is corrected by taking into account any difference observed between data and Monte Carlo efficiencies for identifying high transverse energy electrons and muons. These corrections, in the form of data to Monte Carlo scale factors, are measured using the unbiased leg in Z-boson decays. Another correction comes from the efficiency of the inclusive lepton trigger which is measured in data samples selected with independent sets of triggers.

III. BACKGROUNDS

The sources of background processes considered for this selection are diboson (WW, WZ and ZZ) events, $W\gamma$ events in which the photon is misidentified as lepton, $q\bar{q} \rightarrow Z/\gamma^*$ and QCD production of W boson with multiple jets in which one jet is misidentified as lepton.

The two dominant sources of background dilepton events come from $Z/\gamma^* \rightarrow ee/\mu\mu$ with fake $\not\!\!E_T$ and from W+jets with a fake lepton. They are estimated using data-based methods. The acceptance for the remaining backgrounds, diboson, $W\gamma$ and $Z/\gamma^* \rightarrow \tau\tau$, is based on Monte Carlo predictions.

The diboson decays are simulated with PYTHIA. Their production cross section is taken from the latest NLO MCFM version [4] and CTEQ6 [5] PDF predictions to be $\sigma_{WW} = 11.34 \pm 0.68$ pb, $\sigma_{WZ} = 3.47 \pm 0.21$ pb. For the ZZ events the cross section is taken to be $\sigma_{ZZ} = 3.62 \pm 0.22$ pb with an uncertainty of 20%. $Z/\gamma^* \to \tau\tau$ decays are also simulated with ALPGEN+PYTHIA. The production cross-section is taken to be a proper $\sigma_{Z_{\tau\tau}}$ corresponding to each different Z boson + number of jets process, multiplied by a K-Factor of 1.4. $W\gamma$ decays are simulated with Baur Monte Carlo. The production cross section is taken to be $\sigma_{W\gamma} = 32 \pm 3.2$ pb, multiplied by a K-Factor of 1.36 ($W\gamma \to e\nu$) and 1.34 ($W\gamma \to e\nu$). A conversion inefficiency scale factor SF=1.2 ± 0.12 is applied to the electrons of $E_T < 40$ GeV. The WW, $W\gamma$ and $Z/\gamma^* \to \tau\tau$ jet multiplicity spectra are corrected to account for discrepancies observed between data and Monte Carlo in the Z-boson decays using jet bin dependent, or N_{jet}, scale factor.The uncertainty of the Monte Carlo based backgrounds comes from the convolution of the Monte Carlo statistics, uncertainties on the N_{jet} scale factor, lepton identification and jet energy scale (JES) correction.

The contamination from $Z/\gamma^* \to ee/\mu\mu$ decays is estimated by selecting a sample of Z boson decays with high $\not\!\!E_T$ inside the 76-106 GeV/c^2 window, after correcting for the presence of non DY/Z events. The remaining DY/Z contamination is calculated as two separate contributions, events outside the Z window and events inside the Z window, using Monte Carlo to predict the ratio of events in different kinematic regions. For this analysis we use separate data estimates for the different jet bin multiplicities. The uncertainty on this background comes mostly from the limited statistics of Z/γ^* data events with high $\not\!\!E_T$ used to normalize the overall prediction, from the statistics of the Monte Carlo and from the uncertainty in the jet energy scale correction. There is a small contribution to the backgrounds from $Z/\gamma^* \to e\mu$ events that originate from the $Z/\gamma^* \to \mu\mu$ process where the one electron is associated with photon conversion and is identified as electron. These events are predicted using $Z/\gamma^* \to \mu\mu$ Monte Carlo sample.

For the b-tagging DY/Z background estimation, we use a little different way. We estimate the DY/Z + Light Flavor background using the mistag matrix applied to ALPGEN+PYTHIA Monte Carlo events. And DY/Z + Heavey Flavor background is calculated by applying the heavy flavor scale factor in the ALPGEN+PYTHIA Monte Carlo samples.

The background from fake lepton source is calculated by using a large sample of generic jets triggered by the presence of at least one jet with $E_T > 50$ GeV. This sample was used to calculate the lepton type dependent probability, or fake rate, that an object which shares some of the jets and some the high P_T lepton characteristics, can be reconstructed as a good lepton. This probability is parameterized in terms of lepton transverse energy and isolation, and applied to events with only one high transverse energy reconstructed lepton plus a second electron-like or muon-like object. To remove the real lepton contamination in W+jets events the fakeable object is required to fail to at least one real lepton identification cut. The fake lepton contamination to the top candidate sample is calculated by weighing each "lepton+feakeble" event by the appropriate fake rate depending on the P_T of the fakeable object. The events are required to pass all of the candidate events selection cuts treating the electron or muon-like objects as the second lepton in the event. The uncertainty for the fake background is dominated by the differences observed between fake rates calculated in the jet sample triggered by at least one jet with $E_T > 50$ GeV and similar samples requiring at least one jet with $E_T > 20$, 70 and 100 GeV.

IV. SYSTEMATIC UNCERTAINTIES

A common systematics to signal and background Monte Carlo estimates comes from the uncertainty of the lepton identification scale factors, measured in Z events which have a limited jet activity. The systematic associated to this source is conservatively taken to be 2.2%. Another common systematics is related to the jet energy uncertainties. This is estimated by varying the jet corrections $\pm 1\sigma$ of their systematic uncertainty and measuring the shift of the acceptance. MC-based backgrounds have uncertainty because of the N_{jet} scale factor. These three sources are considered as correlated systematic uncertainties.

Uncorrelated sources of systematic uncertainties are the jet fake systematics, the cross section uncertainties and a 30% systematic uncertainty on the conversion rejection scale factor. The sources that are referred abobe, correlated and uncorrelated, are taken into concideration for the estimation of the systematic uncertainty of the expected number of background events.

For the signal acceptance the systematic uncertainties are due to multiple effects: MC generator, ISF/FSR variation, Color reconnection and PDF's uncertainty. The first two components are calculated by comparing the raw Monte Carlo acceptance of the default $t\bar{t}$ PYTHIA sample to specialized Monte Carlo samples. Table I summarizes the systematic uncertainties that affect the $t\bar{t}$ acceptance.

Source	Systematic Error (%)
$t\bar{t}$ signal acceptance : 4.8	
Lepton ID	2.2
MC Generator	1.9
ISR/FSR	1.3
PDF's	0.6
Color Reconnection	1.2
Jet corrections	3.3
Background modeling : 7.1	
Lepton ID	2.2
Njet scale factor	5.1
Jet corrections	
$(WW/WZ/ZZ)$	17.9/15.2/12.5
$(DY \to \tau\tau)$	16.3
$(DY \to ee + \mu\mu)$	5
$(W\gamma)$	10.0
Fake rate	30
Total	
Sig. + Bkg.	8.6

Source	Systematic Error (%)
$t\bar{t}$ signal acceptance : 6.9	
Lepton ID	2.2
MC Generator	1.9
ISR/FSR	1.3
PDF's	0.6
Color Reconnection	1.2
Jet corrections	3.3
b-tagging	5.0
Background modeling : 2.1	
Lepton ID	2.2
Njet scale factor	5.1
Jet corrections	
$(WW/WZ/ZZ)$	17.9/15.2/12.5
$(DY + LF)$	5.5
$(DY + HF)$	9.4
$(W\gamma)$	10.0
Fake rate	30
Mistag Matrix	9.4
Heavy Flavor SF	7.7
Total	
Sig. + Bkg.	7.2

TABLE I: The left table shows Summary of systematic uncertainties for pre-tagged events and the right table for b-tagged events. The total error is the sum in quadrature of each contribution

V. RESULTS

Table II shows a summary of the pre-tag background estimates for each jet bin after all cuts but before the $\mathrm{H_T}$ and Opposite Charge requirements are applied. The column labeled as $\mathrm{H_T}$ summarizes the expectations in the 2 jet bin after $\mathrm{H_T}$ is applied. The last column contains the candidate events with all cuts applied. This table also shows the total background expectation for the cross section of the 7.4 pb, the sum of the total background and signal expectations (labelled as "Total SM expectation") and the number of candidate events in 9.1 fb^{-1} of data. The total Standard Model expectation is well in agreement with the observed 579 events for the pre-tagged events in the 9.1 fb^{-1}. Figure 2 shows the $\mathrm{t\bar{t}}$ and background prediction, overlaid to the data for the lepton $\mathrm{P_T}$, the dilepton invariant mass, the $\not{E}_T$, the $\mathrm{H_T}$ kinematic distributions, the number of jets distribution and the jet transverse energy spectrum.

Table III shows the total pre-tagged number of background, Standard Model expectation and 9.1 fb^{-1} of data candidate events, divided by lepton flavor contribution. Also Table IV shows the same contribution as the Table III for b-tagged events, divided by lepton flavor contribution.

The cross section is calculated as:

$$\sigma_{\mathrm{t\bar{t}}} = \frac{\mathrm{N_{obs}} - \mathrm{N_{bkg}}}{\sum_{\mathrm{i}} \mathcal{A}_{\mathrm{i}} \mathrm{x} \mathcal{L}_{\mathrm{i}}} \tag{1}$$

where $\mathrm{N_{obs}}$ is the number of dilepton candidate events, $\mathrm{N_{bkg}}$ is the total background and the dominator is the weighted sum of the corrected acceptance for each dilepton category $\mathcal{A}_i$ multiplied by the luminosity relative to that category $\mathcal{L}_i$. Different luminosity is used as the single leptons in a given category require CDF subdetectors to be fully functional. The total denominator is 55.7540 $\pm$0.2581 pb^{-1} for the pre-tagged events and 31.6023 $\pm$ 0.1866 pb^{-1} for the b-tagged events.

For $\mathrm{t\bar{t}}$ events in the dilepton channel, we find the cross sections of:

$$\sigma_{\mathrm{t\bar{t}}} = 7.60 \pm 0.44_{\mathrm{stat}} \pm 0.52_{\mathrm{syst}} \pm 0.47_{\mathrm{lumi}}\ \mathrm{pb}$$

for 579 pre-tagged signal candidate events

CDF II preliminary (9.1 fb^{-1})

Pre-tagged Dilepton Control Sample and Signal Events per Jet Multiplicity					
Source	0 jet	1 jet	$\geq$ 2 jet	H_T>200 GeV	H_T>200 GeV, OS
WW	381.6 ± 33.4	87.0 ± 9.6	29.2 ± 6.1	18.5 ± 3.7	18.0 ± 3.6
WZ	29.6 ± 2.6	30.2 ± 2.1	10.5 ± 1.7	8.3 ± 1.4	5.7 ± 1.0
ZZ	23.3 ± 1.7	10.2 ± 0.8	5.2 ± 0.8	4.4 ± 0.6	3.7 ± 0.5
Wγ	88.6 ± 22.5	24.3 ± 6.8	5.9 ± 2.3	0.7 ± 0.8	0.7 ± 0.8
DY$\rightarrow \tau\tau$	17.0 ± 3.2	55.6 ± 9.6	39.3 ± 9.3	22.4 ± 4.0	21.9 ± 3.9
DY$\rightarrow ee + \mu\mu$	144.0 ± 14.3	132.4 ± 21.0	84.0 ± 22.3	40.6 ± 5.6	40.6 ± 5.6
Fakes	115.8 ± 33.9	139.0 ± 37.1	133.3 ± 35.3	89.0 ± 23.6	64.3 ± 17.2
Total background	799.9 ± 79.4	478.9 ± 60.4	307.3 ± 54.2	183.8 ± 27.3	155.0 ± 21.6
$t\bar{t}$ ($\sigma = 7.4$ pb)	2.2 ± 0.2	55.8 ± 2.7	440.5 ± 21.0	423.6 ± 20.2	412.5 ± 19.7
Total SM expectation	802.0 ± 79.5	534.7 ± 63.1	747.8 ± 75.0	607.4 ± 47.1	567.5 ± 40.9
Observed	777	553	777	625	579

TABLE II: Summary table of background estimates, pre-tagged $t\bar{t}$ predictions and events in 9.1 fb^{-1} of data for each jet bin after all cuts but before the H_T and Opposite Charge requirements are applied and in the 2 jet bin after applying only the H_T cut. The last column contains the candidate events with all cuts applied. The quoted uncertainties are the quadratic sums of the statistical and systematics uncertainties.

CDF II preliminary (9.1 fb^{-1})

$t\bar{t}$ Dilepton Signal Events per Dilepton Flavor Category before b-tagging				
Source	ee	$\mu\mu$	eμ	$\ell\ell$
WW	5.0 ± 1.0	3.8 ± 0.8	9.1 ± 1.8	18.0 ± 3.6
WZ	2.6 ± 0.4	1.6 ± 0.3	1.5 ± 0.3	5.7 ± 1.0
ZZ	1.7 ± 0.3	1.3 ± 0.2	0.7 ± 0.1	3.7 ± 0.5
Wγ	0.7 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.8
DY$\rightarrow \tau\tau$	5.3 ± 1.0	5.2 ± 1.0	11.5 ± 2.1	21.9 ± 3.9
DY$\rightarrow ee + \mu\mu$	21.9 ± 4.1	13.2 ± 2.4	5.5 ± 1.5	40.6 ± 5.6
Fakes	12.4 ± 3.8	15.1 ± 4.9	36.8 ± 11.3	64.3 ± 17.2
Total background	49.7 ± 6.8	40.1 ± 6.1	65.2 ± 12.6	155.0 ± 21.6
$t\bar{t}$ ($\sigma = 7.4$ pb)	97.6 ± 4.7	93.0 ± 4.5	222.0 ± 10.6	412.5 ± 19.7
Total SM expectation	147.3 ± 10.9	133.1 ± 10.2	287.1 ± 23.1	567.5 ± 40.9
Observed	147	147	285	579

TABLE III: Summary table by lepton flavor content of pre-tagged background estimates, $t\bar{t}$ predictions and final candidate events in 9.1 fb^{-1} of data. The quoted uncertainties are the quadratic sums of the statistical and systematics uncertainties.

CDF II preliminary (8.8 fb^{-1})

$t\bar{t}$ Signal Events with the tight SecVtx b-tag				
Source	ee	$\mu\mu$	eμ	$\ell\ell$
WW	0.13 ± 0.06	0.13 ± 0.05	0.33 ± 0.10	0.59 ± 0.15
WZ	0.04 ± 0.02	0.05 ± 0.02	0.05 ± 0.02	0.13 ± 0.03
ZZ	0.14 ± 0.03	0.12 ± 0.03	0.03 ± 0.01	0.29 ± 0.06
DY+LF	1.08 ± 0.12	1.15 ± 0.15	0.55 ± 0.06	2.78 ± 0.31
DY+HF	0.97 ± 0.10	1.07 ± 0.10	0.44 ± 0.06	2.49 ± 0.20
Fakes	1.95 ± 0.70	4.32 ± 1.74	9.34 ± 3.13	15.62 ± 4.61
Total background	4.30 ± 0.74	6.85 ± 1.76	10.75 ± 3.13	21.90 ± 4.66
$t\bar{t}$ ($\sigma = 7.4$ pb)	55.64 ± 3.90	52.02 ± 3.64	126.23 ± 8.76	233.88 ± 16.17
Total SM expectation	59.94 ± 4.53	58.87 ± 5.08	136.98 ± 11.63	255.78 ± 20.52
Observed	53	68	125	246

TABLE IV: Summary table by lepton flavor content with SecVtx b-tagging, of background estimates, $t\bar{t}$ predictions and observed events in data corresponding to an integrated luminosity of 8.8 fb^{-1} for $t\bar{t}$ signal events. The quoted uncertainties are the sum of the statistical and systematics uncertainty.

$$\sigma_{t\bar{t}} = 7.09 \pm 0.49_{\rm stat} \pm 0.52_{\rm syst} \pm 0.43_{\rm lumi}\ \rm pb$$

for 246 secondary vertex b-tagged signal candidate events

where the first uncertainty is statistical, the second is the convolution of the acceptance and background systematics and the third comes from the 6% uncertainty in the luminosity measurement.

In the Figure 3, the left plot shows the number of candidate events in 0, 1, $\geq$2jet events together with a histogram representing the component of the background for the pra-tagged events. And the right plot shows the number b-tagged events in 1jet control region and signal candidate events. The yellow band gives the $t\bar{t}$ contribution for a cross section of 7.4 pb. The red hatched area is the uncertainty in the total background estimate.

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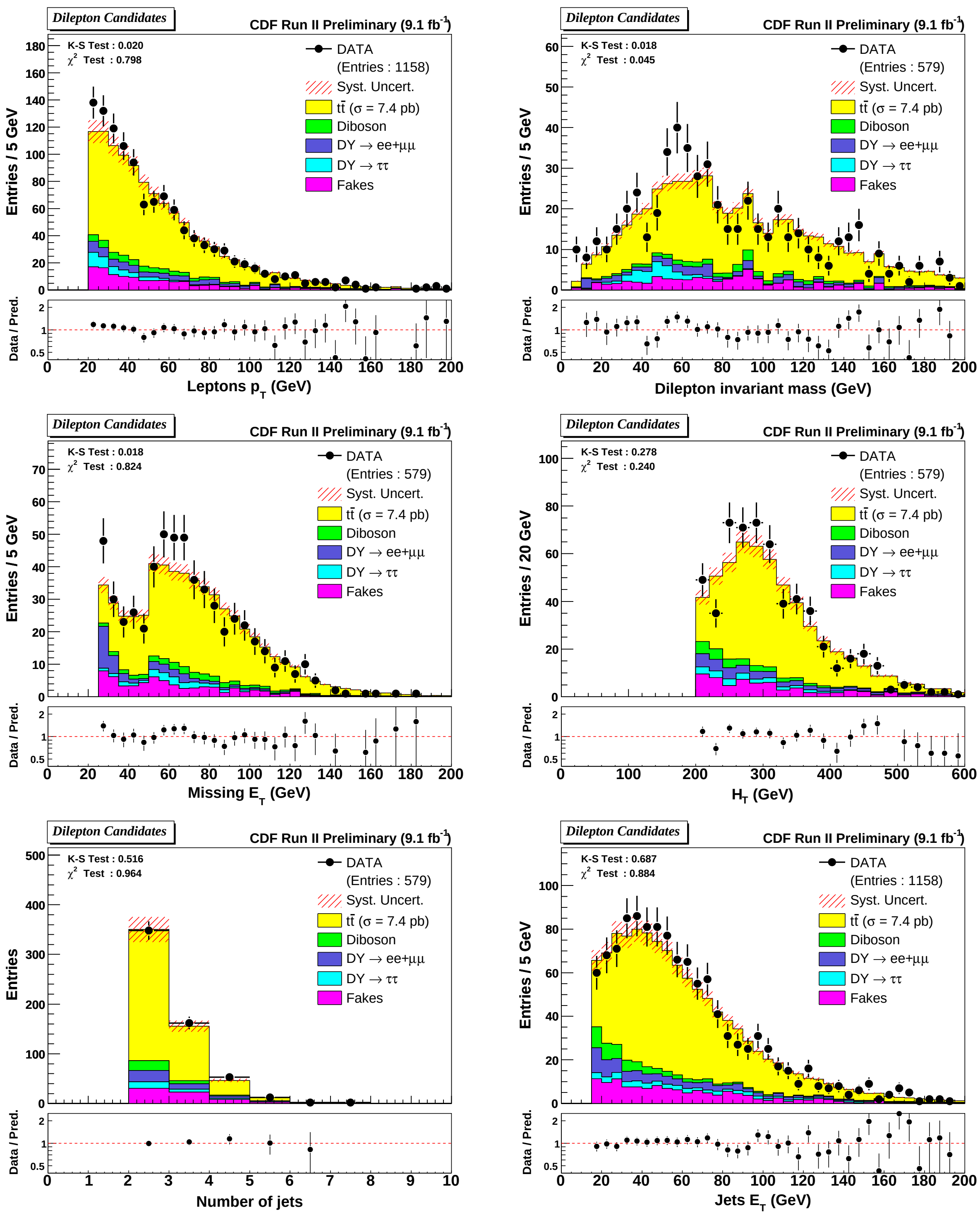

FIG. 1: From top left to bottom right: background and top signal predictions, overlaid to data, for the lepton transverse energy spectrum, the dilepton invariant mass, $\not\!\!E_T$, $\mathrm{H_T}$ distributions, the number of jets distribution and the jet transverse energy spectrum in 9.1 fb^{-1} pre-tagged top DIL candidate events.

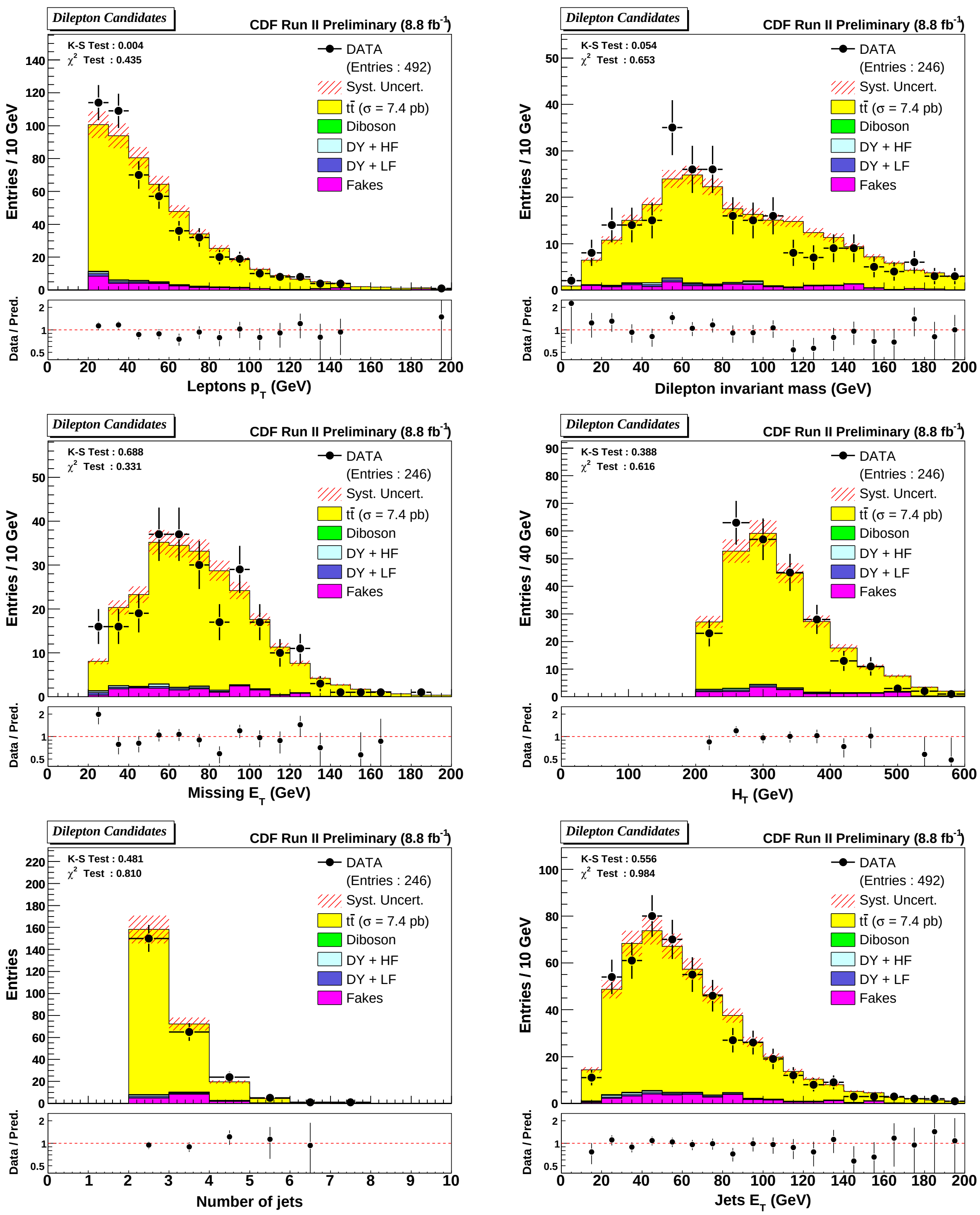

FIG. 2: From top left to bottom right: background and top signal predictions, overlaid to data, for the lepton transverse energy spectrum, the dilepton invariant mass, $\not{E}_T$, H_T distributions, the number of jets distribution and the jet transverse energy spectrum in 4.8 fb^{-1} b-tagged top DIL candidate events.

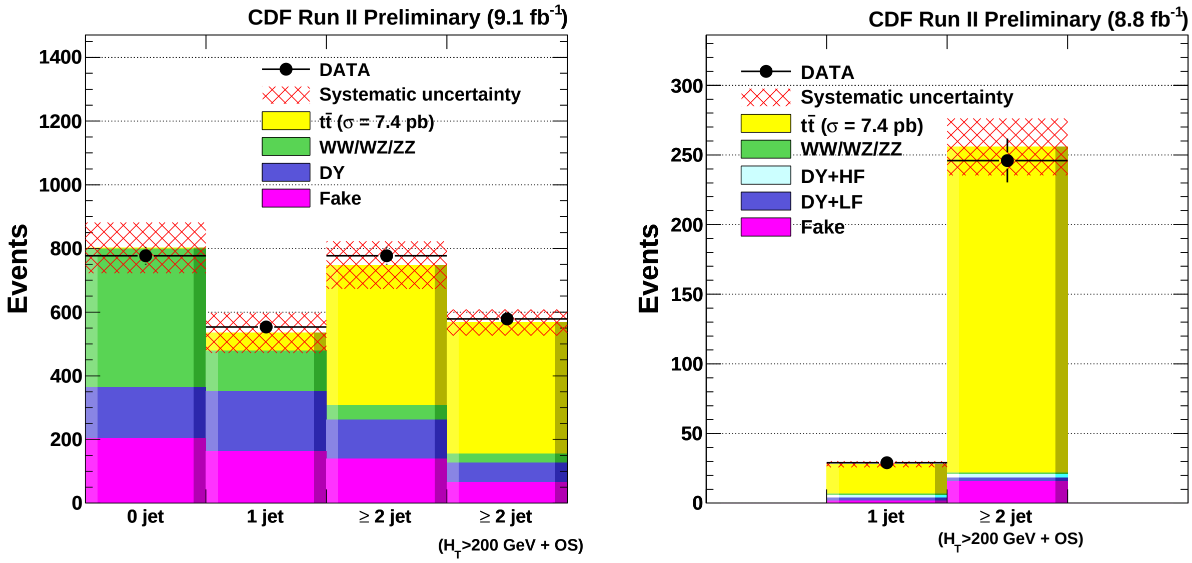

FIG. 3: Observed dilepton candidate events (black point) by jet multiplicity for the pre-tagged(Left) and b-tagged(Right) events. The colored histogram represents the background contribution for an assumed $\sigma_{t\bar{t}}$ = 7.4pb. The red hatched area is the uncertainty in the total background estimate.